9 Study of πK atoms

C. Amsler, A. Benelli, and J. Rochet

(DIRAC Collaboration)

The main initial goal of the DIRAC experiment was to produce $\pi^+\pi^-$ atoms (pionium) and to measure the $\pi\pi$ scattering lengths a_0 and a_2 (isospins 0 and 2) [1]. The difference in the scattering lengths was measured,

$$|a_0 - a_2| = 0.2533 \pm 0.0109\ m_\pi^{-1}$$

based on the observation of 21'227 $\pi^+\pi^-$ atoms. This value corresponds to a mean life of 3.15 ± 0.28 fs. Details can be found in ref. [2].

We joined the DIRAC collaboration in 2007 with the goal to search for πK atoms and to measure the πK scattering lengths $a_{1/2}$ and $a_{3/2}$ (isospins 1/2 and 3/2).

An artist's view of the DIRAC spectrometer and a photograph of the experiment in the CERN-PS-South Hall is shown in figures 9.1 and 9.2, respectively. The 24 GeV/c proton beam passes through a thin target (such as 100 μm Ni). The secondary particles traverse a scintillation fiber detector (SFD). The secondary hadrons produced in target are analyzed in a double-arm magnetic spectrometer measuring the momentum vectors of two oppositely charged hadrons. The spectrometer is slightly tilted upwards with respect to the proton beam. Electrons and positrons are vetoed by N_2-Čerenkov detectors (N) and muons by their signals in scintillation counters (Mu) behind steel absorbers. The preshower detector (PSh) provides an additional electron/hadron separation to the N_2-Čerenkov. Details can be found in previous annual reports and in ref. [3].

In 2007 we modified the DIRAC setup to study πK atoms while at the same time collecting more data for $\pi\pi$ atoms. In both arms the N_2-Čerenkov counters were cut to leave space for heavy gas (C_4 F_{10}) Cerenkov detectors (HG). They identify pions with an efficiency of more than 99% while not responding to kaons nor to (anti)protons. On the left side we installed an aerogel Čerenkov detector (Ae) to identify kaons and reject protons. The detector consists of two modules with refractive index 1.015 and one module with refractive index 1.008 to cover the high momentum range of kaons between 5.5 and 8 GeV/c. Our group has developed and built the 37ℓ aerogel Čerenkov counter [4] and the gas system for the C_4F_{10} counters [5].

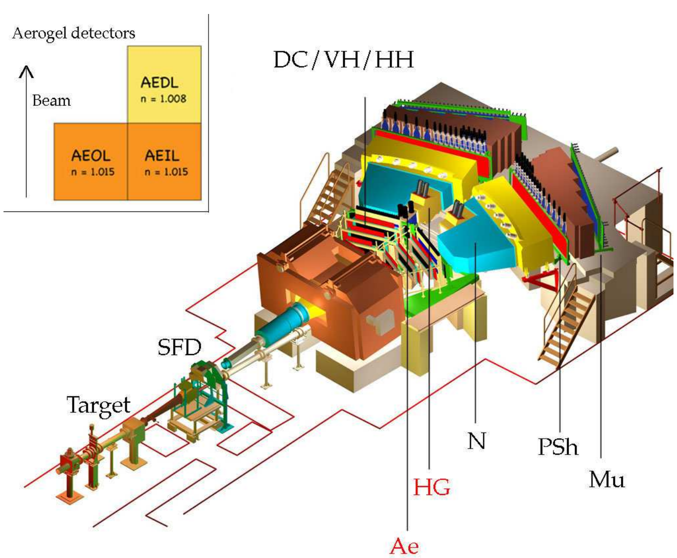

FIG. 9.1 – DIRAC spectrometer:
SFD: scintillating fibre detector, DC: drift chambers, VH (HH): vertical (horizontal) scintillating hodoscopes, PSh: preshower, Mu: muon counters, Ae: aerogel, and HG: heavy gas and N: N_2-Čerenkov counters.
The inset shows the arrangement of the aerogel modules.

FIG. 9.2 – The DIRAC apparatus.

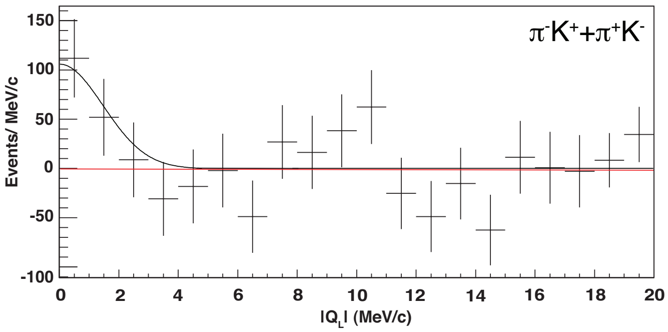

FIG. 9.3 – Distribution of the πK relative momentum in the c.m.s system after background subtraction. A Gaussian fit (solid line) illustrates the signal distribution.

Using only the downstream part of DIRAC for tracking we published the first evidence for πK atoms [6, 7]. A signal of 173 $\pm$ 54 (3.2σ) πK-pairs was observed at very low relative momenta (typically $|Q_L| < 3$ MeV/c in the c.m.s system), see Fig. 9.3. The evidence was strengthened by the simultaneous observation of interacting unbound Coulomb-pairs from which the fraction of expected bound pairs can be calculated. The latter is in excellent agreement with the number of observed atoms. This result corresponds to a lower limit on the mean life of πK-atoms of 0.8 fs in the 1s-state (confidence level of 90%), which translates to [6, 7]:

$$|a_{1/2} - a_{3/2}| < 0.58\ m_\pi^{-1}.$$

More data was collected in 2008 – 2011 from which the total number of reconstructed πK atoms will be around 600. Assuming the central value as in 2007 the significance will increase to 5.3σ corresponding to an uncertainty of about 25% on $|a_{1/2} - a_{3/2}|$.

In 2012 DIRAC also studied the energy splitting ΔE between the pionium $2p$- and $2s$-states by mean of the following method: pionium atoms produced in the target interact with an applied electric field and some of them leave the target in the $2p$-state. The decay into $\pi^0\pi^0$ is forbidden from p-states and hence the main decay process is the $2p - 1s$ radiative transition with subsequent annihilation from $1s$ into $\pi^0\pi^0$. Thus the mean life of the atom in the $2p$-state is determined by radiative transition, $\tau(2p) \simeq 12$ ps, which is much slower than annihilation from the $1s$-states. We refer to these $2p$-states as *long-lived* 2π atoms. One then measures ΔE by observing the field dependence of the number of long-lived 2π atoms breaking up into $\pi^+\pi^-$ pairs in a second foil downstream of the production target. This measures the combination $2a_0 + a_2$. Combined with the measurements from the $1s$-state, the $\pi\pi$ scattering lengths a_0 and a_2 can be determined separately.

Data taking for the DIRAC experiment was completed at the end of 2012 and the apparatus was subsequently dismantled.

[1] B. Adeva *et al.* (DIRAC Collaboration), Phys. Lett. **B 704** (2011) 24.

[2] A. Benelli, EPJ Web of Conferences **37** (2012) 01011, doi: 10.1051/epjconf/20123701011.

[3] B. Adeva *et al.* (DIRAC Collaboration), Nucl. Instrum. Methods in Phys. Res. **A 515** (2003) 467.

[4] Y. Allkofer *et al.*, Nucl. Instr. Meth. in Phys. Res. **A 582** (2007) 497; Y. Allkofer *et al.*, Nucl. Instr. Meth. in Phys. Res. **A 595** (2008) 84; C. Amsler, Proc. of Science PoS EPS-HEP (2009) 078.

[5] S. Horikawa *et al.*, Nucl. Instr. Meth. in Phys. Res. **A 595** (2008) 212.

[6] B. Adeva *et al.* (DIRAC Collaboration), Phys. Lett. **B 674** (2009) 11.

[7] Y. Allkofer, PhD Thesis, University of Zurich (2008).